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## Design of Aircraft Cable Fault Diagnose and Location System Based on Aircraft Airworthiness Requirement

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### Abstract

Aircraft cable have the special status in aviation domain, with the improvement of aircraft performance requirements, the amount of the single wire is also increasing gradually. Demanding of its performance and maintaining is increasingly day by day. An aircraft cable fault diagnosis and location system based on Phase Detection Frequency Domain Reflectometry (PDFDR) is presented in this paper, which is used to diagnose and locate the special aircraft cable faults, such as intermittent fault, continuous fault and cross-connect fault. With the threshold denoising method on Hilbert Huang Transform, the studied approach is developed to detect and locate aircraft cable “hard defects” (i.e. opens and shorts) based on Phase Detection Frequency Domain Reflectometry (PDFDR). By analyses the differences of amplitude and phase in superimposed signal which from the incident signal and the reflected signal on defects, the shortage of Phase-Detection Frequency Domain Reflectometry (PDFDR) simply using in locating aircraft cable defects is solved. Utilizing the strong calculating capability and the abundant function library of MATLAB, the signal processing turn to be easily realized, moreover LabVIEW help the system to be more reliable and updated easily.

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**Keywords:** Hilbert Huang Transform; Phase Detection Frequency Domain Reflectometry; hard defects

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## 1. Introduction

Aircraft cable has excellent electrical properties, mechanical properties, chemical stability, and capability of the propellant, can operate stably range from minus 65 Celsius to 200 Celsius temperatures. To meet the airworthiness requirements, many domestic models have chosen such wire. And compared to the past use of nylon wire, to use the wire, stand-alone will relieve about 15% weight and saves wiring space. In recent years, aviation wire has been developed rapidly, many different types, and satisfy the needs of a variety of aircraft wire.

To meet the airworthiness requirements, the safety threat of aging aircraft cables has received extensive national attention, and several methods for cables testing have been developed. Frequency Domain Reflectometry methods send a low-voltage high-frequency sinusoidal signal down the aircraft cable and detect reflections from it. These methods are presently available for detecting opens and shorts cable, and techniques for detecting frays, cold solder joints, and other small anomalies are emerging [1-4]. However, the methods rely on a strong reflection from the fault on the cable, which some facts such as moisture, damaged insulation influence reflection, types of faults detected is difficult by traditional FDR methods.

This paper describes and analyzes one such method, based on Phase Detection Frequency Domain Reflectometry (PDFD-R), which can detect and locate aircraft cable “hard defects” easily. The method of this paper described is as follows:

- Confirm the incident signal with an optimal bandwidth;
- A filtering algorithm to remove noises from signals with EMD is used;
- The distance of aircraft cable “hard defects” is predicted;
- The types of aircraft cable “hard defects” is judged by analyzing the differences of amplitude and phase in superimposed signal.

## 2. Methods based on PDFDR

### 2.1. PDFDR analysis

The traditional PDFDR system sends a set of stepped frequency sine waves down the wire, where they are reflected from anomalies on the cable. Unlike TDR, the PDFDR isolates the reflected wave from the incident wave. And the PDFDR method measures the phase difference which is proportional to time delay [1-4]. This phase difference can be detected using a frequency multiplier (mixer), which multiplies the two signals together. The output of the mixer includes two frequencies: the sum of the incident and reflected frequencies, and the difference of these two frequencies. Since the incident and reflected frequencies are the same, their sum will be the second harmonic: the one is a high-frequency signal which is automatically filtered out by a low-frequency analog-to-digital (A/D) converter and the other one is a dc signal which is measured by the PDFDR system. As the frequency is stepped, the dc voltage at the output of the mixer has a sinusoidal (or sum of sine waves) signature that can be used to determine the distance of aircraft cable “hard defects”.

Similar to traditional PDFDR method, the method of this paper described ensuring the distance of cable defects by detecting phase offset of the superimposed signal on defects: Firstly, the reflected signal is isolated from the incident signal by the second directional converter and FFT. Secondly, single spike at a location called Peak is got. Thirdly, a dc voltage at the mixer output signal will be detected, and we will use it to locating aircraft cable defects ( $L$ ) which get from the location of this Peak by:

$$L = \frac{1}{2} \left( \frac{\text{Peak} - 1}{N_{FFT} - 1} \right) \left( \frac{N_F - 1}{f_2 - f_1} \right) v_p \quad (1)$$

Where:

Peak: an integer value which from the peak value in the FFT;

$N_{FFT}$ : number of points in the FFT;

$N_F$ : number of frequencies in the PDFDR;

$f_1$ : start frequency of the PDFDR;

$f_2$ : stop frequency of the PDFDR;

$v_p$ : velocity of propagation in the cable.

Fig.1 shows the location of the maximum peak is used with (1) to find the predicted length of the cable.

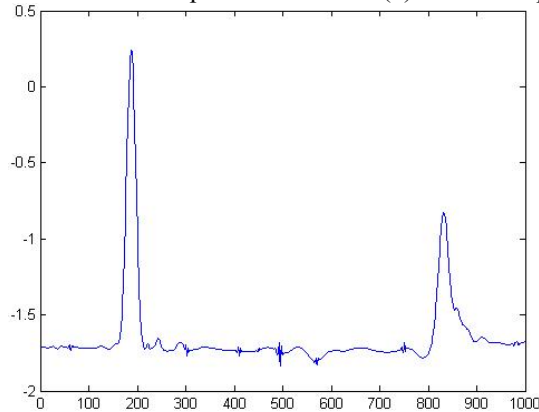


Fig.1. Peak (based on a 2048-point FFT) as a function of cable length for the cable

Generally, the range of the PDFDR method is limited by the Nyquist Criterion which is a basic premise of communication theory. It requires that a sinusoidal signal must be sampled twice per period in order to take an accurate FFT [1-3]. The range is reached when only two frequency samples are taken per cycle of the dc voltage waveform. Since the signal must travel both down the cable and back, the maximum cable length that can be measured is half the allowable range.

The propagation speed  $v_p$  in the aircraft cables can be measured by TDR [2], the signal propagation speed in several cable types is about  $0.66C \sim 0.71C$  ( $C = 3 \times 10^8 \text{ m/s}$ ). In this paper, the emission frequency step ( $\Delta f$ ) is 10MHz, the maximum length that can be measured in theory is 120m, the sampling number in one period is 2048, and the measurement accuracy in period is 2.5mm. All of these parameters fit the accurate demand of aircraft cable defects detecting method including short lengths cable.

## 2.2. The establishment of the incident signal bandwidth

One of the goals of this Cable defects detecting method is to determine an optimal sweep frequency sinusoidal signal bandwidth. TDR and PDFDR methods are strongly related [2]. In theory, TDR provides information on the reflected wave on the cable over “infinite” bandwidth. In practice, this “infinite” bandwidth is very large, but limited by the rise time of the pulse and the speed of the sampling circuitry. In theory, PDFDR methods provide identical information over a selected subset of frequencies that usually a much smaller bandwidth than TDR. In practice, differences in the sensitivities and accuracy of the electronics can cause variation in how the different systems perform. Still, it is useful to know that data received using a TDR can be replicated using a PDFDR method, and vice versa.

The coaxial cable (RG104) is used in this paper, which lengths are 10m and defects are located around the middle of the 5m within a few millimeters. According to Hilbert Huang Transform, the intricate data can be decomposed into a finite and small number of intrinsic mode functions (IMFs) that reflect local properties of the signal and admit well-behaved Hilbert transform. The Hilbert transformation of those

IMFs provides an energy-frequency-time distribution giving sharp and meaningful identifications of imbedded features. Unlike typical spectral analysis approaches, where the basis functions are fixed and pre-determined a priori, the HHT method adaptively decomposes the signal into oscillating components extracted from the data itself.

Therefore, the IMF functions of the coaxial cable (RG104) related TDR reflection is used to determine an optimal sweep frequency sinusoidal signal bandwidth. Fig. 2 shows the marginal signal energy versus frequency of the first IMF functions. The energy distribution of typical reflection shows that most of the signal energy is located in the neighborhood of 50 MHz.

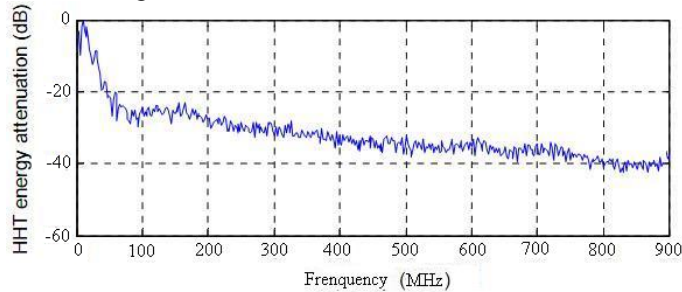


Fig.2 Mean marginal frequency distribution of all signals in IMF1

Thus, at least 50 MHz bandwidth is used for cable defects detecting method.

### 2.3. Denoising method based on Empirical Mode Decomposition (EMD)

The method of Empirical Mode Decomposition (EMD) that can analyze the nonlinear and non-stationary signal is introduced to decompose superimposed signal, which is superposition of signal from the incident signal and the reflected signal on defects [5, 6].

The premise of the EMD technique is to produce the data that describes the signal characteristic time scales called Intrinsic Mode Functions (IMF) extracted from the data itself. Because the approach is algorithmic, it does not allow an analytic expression of the different components of the EMD in a closed form. There are two conditions for a given function to be considered as an IMF:

- In the whole dataset, the number of extreme and the number of zero-crossings must either equal or differ at most by one;
- At any point, the mean value of the envelope defined by the local maxima and the envelope defined by the local minima is zero.

The EMD is also known as the sifting process, is described as follows:

- Find all the local maxima and the minima of the signal, connect the maxima forming a curve as the upper envelope  $X_{max}$ , and repeat the procedure to the minima forming the lower envelope  $X_{min}$ ;
- Identify the mean  $m_1(t)$ , and subtract  $m_1(t)$  from the original signal  $h_1(t)$ , regard  $h_1(t)$  as the new signal:

$$h_1(t) = X(t) - m_1(t) \quad (2)$$

- Generally,  $h_1(t)$  is not a stable time scales data, repeat the steps (1),(2) until  $h_1(t)$  meet the IMF's conditions, then  $C_1(t) = h_1(t)$ ;
- $C_1(t)$  is separated from the  $X(t)$ ,  $R_1(t) = X(t) - C_1(t)$ ;

#### 2.4. Types of “hard defects” detected

Reflection coefficient is the basis of several measurements common in the wire and cable industry. All reflectometry methods depend on a strong reflection from the defects on the cable in order to locate it. Opens and shorts defects provide the largest reflection coefficient, so the key of coaxial cable “hard defects” judgment is analyze the reflection coefficient on changing impedance.

Fig. 3 shows the sketch of coaxial cable whose length is  $L$ .

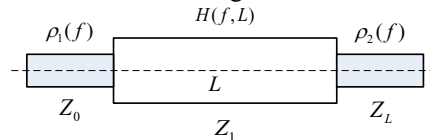


Fig.3 Sketch of coaxial cable with import and load impedance

Where:

$Z_1$ : characteristic impedance of coaxial cable;

$H(f, L)$ : propagator of the incident signal;

$Z_0$ : input impedance of coaxial cable;

$Z_L$ : load impedance of coaxial cable;

$\rho(f)$ : reflection coefficient.

Generally,  $\rho(f)$  is demonstrated by the change in impedance. When an electrical signal is transmitted down a transmission line, the electrical wave travels without interference as long as there are no discontinuities within the line. Discontinuities are changes in the impedance within the transmission line, and acts as a barrier to the flow of the electrical signal. These barriers cause the electrical signal to bounce back towards the signal source. This is called a reflected wave and is in the opposite direction of the signal being transmitted. The amount of reflected signal is a function of the change in impedance within the transmission line as shown in Equation 3:

$$\rho(f) = \frac{Z_R - Z_I}{Z_R + Z_I} \quad (3)$$

Where:

$Z_R$ : reflected impedance;  $Z_I$ : incident impedance.

When the cable impedance equals the input impedance there is no reflected signal, and reflection coefficient is 0.

If the cable impedance is higher than the input impedance the reflected signal is positive. In the case of an open circuit the impedance is infinitely high and the reflected signal is equals the input signal and has the same polarity. Thus  $V_R$  and  $V_I$  are equal in magnitude and of the same polarity so the resultant reflection coefficient is 1.

If the cable impedance is lower than the input impedance the reflected signal is negative. In the case of a short circuit the impedance is infinitely low and the reflected signal equals the input signal but is opposite in polarity. Thus  $V_R$  and  $V_I$  are equal in magnitude and opposite polarity so the resultant reflection coefficient is -1. Thus the range of reflection coefficient is +1 to -1, as table 1:

Table 1. Reflection coefficients and Amplitude of superimposed signal on two types of “hard defects”

Type of “hard defects”	Reflection coefficient	Amplitude of superimposed signal
Opens defects	1	Step up
Shorts defects	-1	Step down

### 3. The experimental equipment hardware

The system has been controlled either with an Industrial Personal Computer via a data acquisition system ZTC450 when the arbitrary waveform generators Acqiris DP1400 send incident signal to the aircraft cable.

- Signal generator, Acqiris DP1400 high-performance PCI signal generator is used, whose sampling frequency is 1GS/s, and bandwidth is 1GHz;
- Signal acquisition, ZTEC450 PCI high speed data acquisition card is used, whose sampling frequency is 1GS/s;
- Main controller, portable industrial control computer produced by Advantech Company is used.

Working process of this system is as follows: Firstly, connecting signal generator, signal acquisition card and tested coaxial cable by the T-type BNC connector. Secondly, set ZTEC signal generator. Thirdly, collect the signal which is superimposed by reference signal and reflected signal into signal acquisition card. And then these signals are stored in RAM (random access memory) through DMA (direct memory access) channel, avoiding the intervention of the central processor unit. Finally, the data of the test result in RAM are read into the hard disk of the main controller and processed by LabVIEW and MATLAB software.

### 4. The experimental equipment software

#### 4.1. Block diagram of aircraft cable defects detecting method



Fig.4 the Aircraft Wire Fault Detecting system

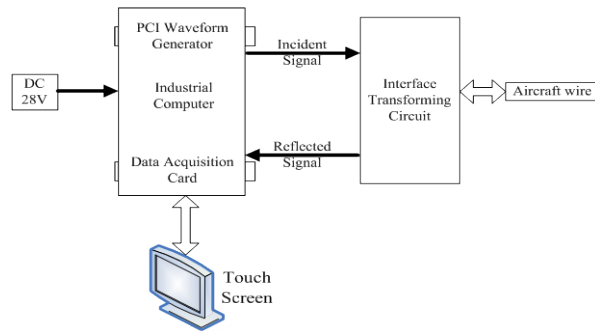


Fig. 5 The block diagram hardware based on PDFDR

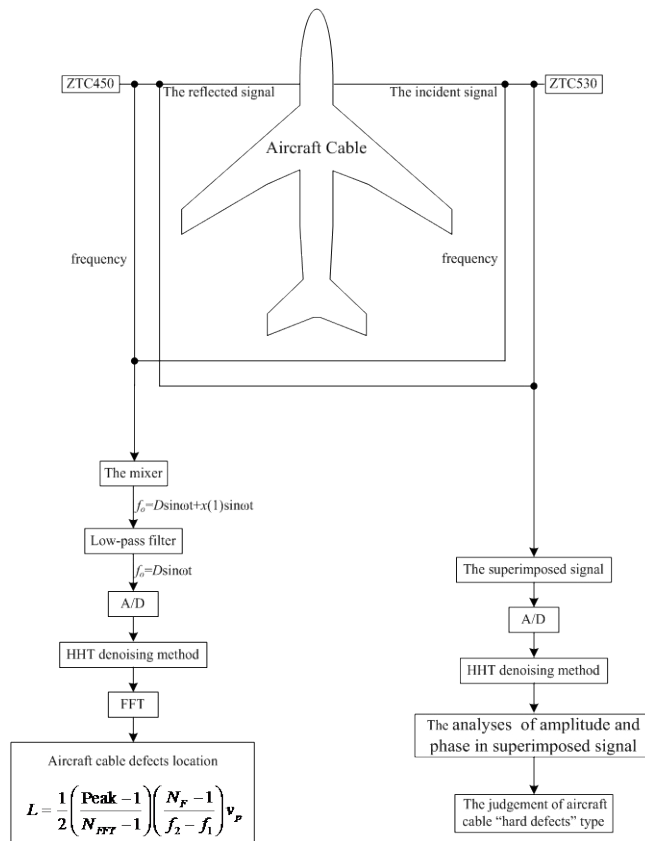


Fig. 6 Block diagram of the method based on PDFDR

#### 4.2. Incident signal generation

The incident signal can be originated by importing .csv format file which is generated in the MATLAB into the soft-panel of the ZTEC signal generator. System front panel is shown in Fig. 7.

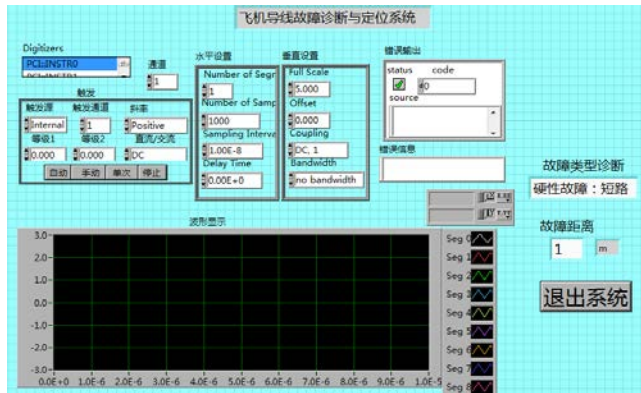


Fig.7 System front panel

#### 4.3. Data of superimposed signal acquisition

Data acquisition is closely related to ZTEC450 ADC (Analog Digital Converter) Interface. In this paper, the data of superimposed signal can be gained from Interface Converter Circuit. Data acquisition module is used to control the whole data acquisition system, including parameter configuration, state switch, result output, etc. The block diagram of data acquisition is shown in Fig. 8.

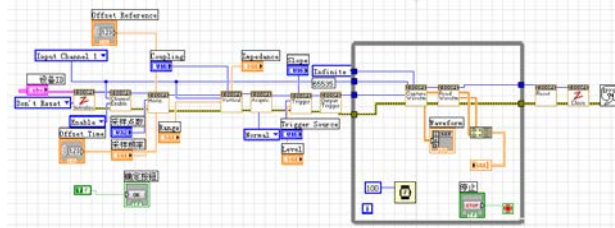


Fig.8 Data acquisition program on LabVIEW

#### 4.4. Detect and locate cables “hard defects” program on LabVIEW

With the denoising method based on EMD, we get smooth superimposed signal data from defects at approximately 5m, the Fig. 9 shows shorts, the Fig. 10 shows opens.

At the same time, locating cables “hard defects” can be achieved by automatically determining the extreme points of Peak (based on a 2048-point FFT), in section2.1, the location of the maximum peak will be utilized to accurately measure the propagation delay of the reflected signal, which is then to be converted into the fault location with knowledge of the velocity of propagation.



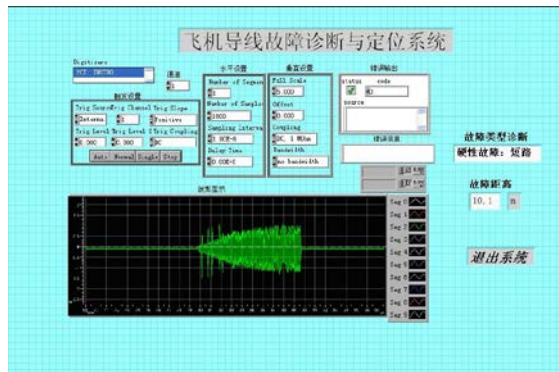


Fig. 9 The smooth superimposed signal whose types of aircraft cable is shorts

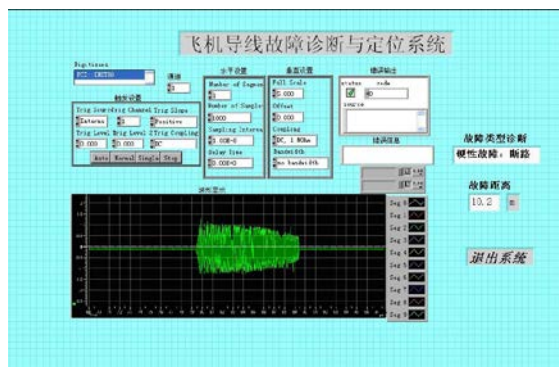


Fig. 10 The smooth superimposed signal whose types of aircraft cable is opens

## 5. Results

The incident sweep frequency sinusoidal signal which produced by the Acqiris DP1400 arbitrary waveform generators, and the emission frequency step is 10MHz. the length of coaxial cable (RG104) is 10m, which defects locate at 5m. The detected superimposed signal which is superposition of signal from the incident signal and the reflected signal on defects is detected by the ZTC450 Digital Storage Oscilloscope. The LabVIEW and Matlab 7.0 can be used to denoise, locate and detect aircraft cable “hard defects” (i.e. opens and shorts).

After the reflected signal to return to the system, and the ZTC450, Acqiris DP1400 to stabilize, the computer reads the analog dc voltage from the mixer output. Since the frequency response of the superimposed signal is somewhat nonlinear, the denoising method can reduce the noise with Matlab 7.0 EMD mathscript. It repeats these steps for each stepped frequency until all signal have been sampled. And then takes the FFT of the dc samples from the mixer, searches for the maximum peak in the transform, and computes the length or judge the type of aircraft cable “hard defects”. Aircraft cable opens defects test results are saved as shown in table II.

Table 2. Aircraft cable opens defects test results and error

Test number	Distance of defects(m)	Error(m)
1	10.1	0.1
2	10.2	0.2
3	10.2	0.2
4	10.1	0.1

## 6. Conclusion

This paper has described a new method based on PDFDR and EMD for judging the types of aircraft cable “hard defects”, which uses concepts from bandwidth determine. The experimental results show that can be effective tools for judging on short lengths of cable.

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